Thermokinetics Characterization of Kerosene/RP–1 Combustion

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Russian-built kerosene-fueled rocket engines such as RD–170 or its U.S.-proposed counterparts such as RD–704 or the Bantam engine series, have been identified as potential candidates to fly the single-stage-to-orbit reusable launch vehicles. In order to support the associated engineering issues, especially the preliminary conceptual design and evaluation of the propellant injectors and thrust chambers using computational fluid dynamics (CFD), accurate and computational efficient models that properly represent the fuel formula, thermodynamics, and combustion kinetics have to be used. Unfortunately, models pertaining to those aspects were underdeveloped.

In this study, based on reported physical-chemical property data, a one-formula surrogate fuel is proposed as a general representation for kerosene and its derived fuels, RP–1 in particular. Its heat capacity, enthalpy and entropy are generated based on available data base and the proposed surrogate fuel formula. The resultant surrogate fuel model and its thermochemical properties are verified by comparing a series of one-dimensional rocket thrust chamber theoretical performance calculations under Russian Engine RD–170 operating conditions. The computed chamber and nozzle exit temperatures and species compositions from the proposed model compared very well with those of using its elemental formula and those from literature. A kerosene/RP–1 combustion kinetics is also proposed based on a quasiglobal kinetics format. Following that format, two global steps are proposed: one for the paraffin portion and another for the naphthene part of the surrogate fuel. The rates of the two global steps are modified directly from those of the straight chain and cyclic global steps according to the paraffin and naphthene split of the proposed surrogate fuel model. A global step making soot directly from the surrogate fuel is also proposed, along with a soot oxidation step originated from a heterogeneous reaction model. The quasiglobal combustion kinetics is closed with a conventional CO-wet mechanism.

The proposed thermal-kinetics models are incorporated into a CFD code, FDNS, for computing the thermo-flowfields of an unielement coaxial-type tripropellant (liquid RP–1/gaseous hydrogen/ gaseous oxygen) injector test performed at the Cryogenic Combustion Laboratory located at Pennsylvania State University. The multiphase FDNS solves simultaneous liquid-droplet-gas dynamics by combining the volume-of-fluid and Eulerian/Lagrangian tracking methods into a unified algorithm for efficient calculations of multiphase free surface and droplet flows at all speeds. The computation predicted reasonable flame structure and combustion efficiency as observed and measured from the test. The thermokinetics model developed in this study is being used to support the Bantam engine development effort.

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Biographical Sketch: Dr. Ten-See Wang is currently a team leader of the Computational Analysis Team in the Fluid Dynamics Branch. He received his Ph.D. from Louisiana State University in 1980. He had previously been affiliated with SAIC, Continuum, SRA, and SECA, Inc. His recent work has been applying CFD methods for propulsion system and launch vehicle environment.

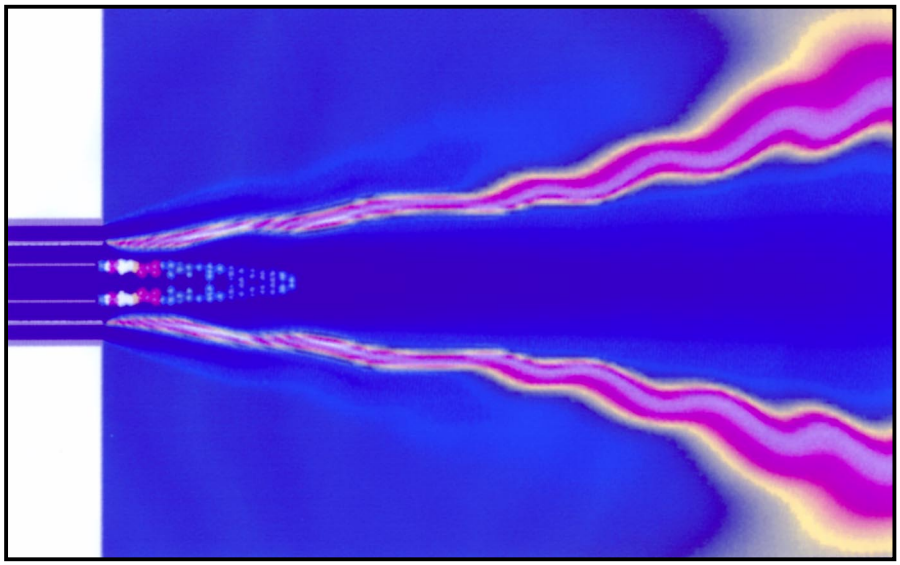

Figure 61.—The computed unielement tripropellant injector temperature contours.